Chapter 1

A Culture of Research Excellence:

Ames in the NACA

"NACA's second laboratory:" until the early 1950s, that was how most people in the aircraft industry knew the Ames Aeronautical Laboratory. The NACA built Ames because there was no room left to expand its first laboratory, the Langley Aeronautical Laboratory near Norfolk, Virginia. Most of Ames' founding staff, and their research projects, transferred from Langley. Before the nascent Ames staff had time to fashion their own research agenda and vision, they were put to work solving operational problems of aircraft in World War II. Thus, only after the war ended--freeing up the time and imagination of Ames people--did Ames as a institution forge its unique scientific culture.

With a flurry of work in the postwar years, Ames researchers broke new ground in all flight regimes--the subsonic, transonic, supersonic, and hypersonic. Their tools were an increasingly sophisticated collection of wind tunnels, flight-test aircraft, and methods of theoretical calculations. Their prodigious output was expressed in a variety of forms--as data tabulations, design rules of thumb, specific fixes, blueprints for research facilities, and theories about the behavior of air. Their leaders were a diverse set of scientists with individual leadership styles, all of whom respected the integrity and quiet dignity of Smith DeFrance, who directed Ames from its founding through 1965.

This culture is best described as Ames' NACA culture, and it endures today. The NACA was founded in 1915, when Americans discovered that their aircraft were inferior to those of the Europeans. The NACA itself had a unique management structure--built around a nested hierarchy of committees that served as a clearinghouse for information about the state of the art in aircraft technology. The heart of the NACA was its executive committee, supported by a main committee of 15, and a wide array of subcommittees formed to address specific problems. Committee seats were coveted by leaders of the aircraft industry, airlines, universities, and military services. In 1917, the NACA built a research laboratory at Langley Field near Norfolk, Virginia, which developed "tunnel vision" around its focus on applied aerodynamics. Whenever the NACA subcommittees could not think of a solution to some aircraft problem, they tasked the research staff at Langley to work on it. Because the NACA committees were strong, its headquarters was weak. Because the NACA was a tiny organization that carefully served the vital needs of more powerful agencies, it was largely free of political mingling.

Because of the way DeFrance patrolled the borders of his laboratory, many scientists at Ames knew little about the larger NACA context in which they pursued their work. Yet the NACA committee culture had a clear impact on the Ames research culture--the profusion of outside collaboration, belief in the value of sophisticated research facilities, appreciation of those who do good science in the cheapest and fastest way, hiring the best people and encouraging them to reinvent themselves as new research areas arise.

]Funding the West Coast Laboratory[

World War II began, for the NACA, early in 1936 when the main committee confirmed the enormity of Nazi Germany's investment in aeronautical research. The NACA learned quickly that Germany had built a research infrastructure six times bigger than the NACA's, that German universities were producing many more trained engineers, and that German aircraft might soon be the best in the world. Well before Germany invaded Poland in 1939, the NACA was on a self-imposed war footing. Yet until then, Congress and the Bureau of the Budget kept NACA planning entrapped in Depression-era politics. The Special Committee on Relations of NACA to

National Defense in Time of War, though formed in October 1936, was unable to formulate any feasible proposals until August 1938.

The Langley laboratory was simply overbuilt. Major General Oscar Westover, chief of the Army Air Corps and chairman of the NACA special subcommittee, wrote that aeronautical research was hampered by "the congested bottleneck of Langley Field."[1] Plans for upgrading the infrastructure of the base went unfunded during the early Depression, and a 1936 deficiency appropriation for new facilities quickly showed how little capacity remained at Langley. There was little room left for new wind tunnels and, more importantly, little extra capacity in the electrical grid to power them. The skies over Norfolk were filled with aircraft from all the military services, and the tarmac at Langley had little extra room for flight-test aircraft.

In October 1938, the NACA formed a new Committee on Future Research Facilities, chaired by Rear Admiral Arthur B. Cook. By 30 December, when Cook's committee submitted its report, the world had become a very different place. Gone was the optimism surrounding the Munich conference in September, as the allies sacrificed Czechoslovakia in a futile attempt at appeasement. Hitler admitted that he had built an air force in direct defiance of the Versailles Treaty, and then occupied Austria without resistance in large part because of his air power. NACA expansion plans finally rode the coattails of general military preparedness funding.

The NACA plans included some expansion at Langley, plus one new aeronautical research laboratory and a second laboratory specializing in propulsion. The NACA site selection committee had sketched out the general conditions for siting a second aeronautical laboratory: that it be on an existing Army or Navy flying field; that it offer year-round flying conditions; that it have adequate electrical power; that it be near sea level; and that it be near an industrial center for easy access to skilled labor and technical supplies. Initially the NACA preferred a location that was inland--isolated from

German or Japanese attack--but then decided those fears were overcome by the need to locate closer to the West Coast aircraft industry.

They picked Moffett Field, in Sunnyvale, California. Moffett Field had been opened by the U.S. Navy in 1933 as a West Coast base for its dirigibles. The Army Air Corps took over Moffett Field in 1935, following the crash of the Navy dirigible U.S.S. Macon, and built a big airfield on the flat marsh lands in the southern portion of San Francisco Bay. Almost half of U.S. aircraft manufacturing was located on the West Coast, within a day's rail journey from Sunnyvale. Yet it was far enough away that industrial engineers could not pester NACA researchers.

Service to industry became an ever larger part of the NACA agenda. Military procurement officers increasingly asked NACA researchers what was possible in the state of the art of aircraft design, then drew up specifications to match the NACA comments. Industrial engineers, with the task of building to these specifications, then brought to the NACA problems for solution and prototypes for testing. Since trips between southern California and the Langley laboratory consumed time and money, manufacturers turned instead to local resources, like the GALCIT wind tunnel in Pasadena. Therein lay the first attack on NACA plans for a second laboratory.

Since its founding in 1927, the Guggenheim Aeronautical Laboratory of the California Institute of Technology (GALCIT) had grown apace with the southern California aircraft industry. Clark Millikan director of GALCIT, in conjunction with famed Caltech aerodynamicist Theodore von Karman, in December 1938 proposed an upgrade to their tunnel. Sensitive to the NACA territory on the spectrum of aeronautical research, Robert A. Millikan, chair of Caltech's executive committee, said this tunnel would be only for applied research, meaning for the application of theory to specific industrial design problems. Millikan proposed construction of a variable-density tunnel, with a 12-foot cross section, and capable speeds up to 400 miles per hour. It would cost only $785,000, far less than the complete NACA second site.

Millikan passed his request along to General Henry "Hap" Arnold, new chief of the Army Air Corps and thus a new member of the NACA. Would Arnold fund the new tunnel at GALCIT to complement work done at Langley and Wright Field? Arnold heard his NACA colleagues argue that talk like this could derail its proposal for a second laboratory, which was working its way through the executive branch and Congress. On the other hand, the military seemed favorably disposed to the GALCIT proposal, and the industry on the West Coast was flexing some lobbying effort in support of it.

NACA opposition to the GALCIT proposal might seem to be mere obstructionism. In postulating the research spectrum in aeronautical science over the years, the NACA had carefully divided the labor with its clients--the military services and industry--rather than contesting roles in basic science with the universities. Before the 1940s, American universities had contributed little besides broadly-trained engineers to American aeronautical development. Now, Millikan again raised the relationship between academia and the NACA, in a dangerous way. First, he associated the NACA with the universities on the basic side of the spectrum, separating it more clearly from the applied research it did for its clients. Second, Millikan proposed that Caltech specifically served the West Coast aircraft industry. To place government-funded research tools in von Karman's hands, NACA officials realized, was to arm a rival in a field that NACA meant to command. So Arnold sided with the NACA, decided to build a new military tunnel at Wright Field, and stopped supporting the GALCIT proposal. When the Millikan proposal failed to win Army support, Congressman Carl Hinshaw, whose district included Caltech, introduced a bill to fund a Caltech wind tunnel. Jerome Hunsaker, then chairman of the NACA, testified that Caltech appealed for government funds only because southern California firms were unwilling to fund a tunnel that would directly serve them. The proposal failed, leaving NACA even more determined to get funding for its Sunnyvale laboratory.

The NACA proposal cleared the next big hurdle--the Bureau of the Budget--and was forwarded to Congress by President Roosevelt on 3 February 1939. Then came the unexpected. The usually friendly House Appropriations Committee approved the expansion at Langley, but reported adversely on the Sunnyvale laboratory. This was the first congressional rejection of any major NACA proposal.

For the first time in its history, the NACA stood between a rock and the pork barrel. The long-time chairman of the House Appropriations Committee, Charles Woodrum of Virginia, always passed along the NACA requests when they emanated from headquarters in Washington or the laboratory in Langley. The NACA never abused Woodrum's assistance, and submitted realistic estimates that were efficiently executed. Woodrum suspected, rightly, that a new laboratory in Sunnyvale would divert funding from Langley. And there were no Congressmen from California on the committee to barter pork. The NACA was unprepared to do politics this new way but learned quickly. On the day Woodrum's committee turned down the Sunnyvale request, NACA executive secretary John Victory wired to Smith DeFrance, then a Langley staffer doing advance work in California: "Entire project disapproved... You proceed quietly and alone and learn what you can for we still have hope."[2]

The NACA started by collecting endorsements. The day after the committee's rejection, General Arnold and Admiral Cook signed a joint statement declaring that "the Sunnyvale research project is emergency in character and of vital importance to the success of our whole program for strengthening the air defense of the United States." NACA chairman Joseph Ames sent this statement to the president and tried, unsuccessfully, to have the Senate reintroduce the NACA proposal.

So the NACA Executive Committee met in June and appointed a Special Survey Committee on Aeronautical Research Facilities, chaired by Charles Lindbergh and composed of General Arnold, Admiral John Towers, and Robert H. Hinkley, chairman of the Civil Aeronautics Authority. During the congressional rehearing of the Sunnyvale proposal, they reached a neat compromise, facilitated by the prestige of Lindbergh and the power of the other members of this Special Committee. Congress approved the NACA proposal for a second laboratory, but deleted the provision establishing it in Sunnyvale. Instead, the NACA had to select a site within 30 days after the bill was passed. The bill passed on 3 August, and Lindbergh's committee reevaluated its list of 54 newly proposed sites. On 19 October 1939 the Lindbergh committee settled, not surprisingly, on the Sunnyvale site. (Lindbergh's evaluation of these sites proved very useful in the fall of 1940, when his committee was also asked to select a site for a new engine research laboratory, which they located in Cleveland.)

The turmoil over establishing the NACA's second laboratory had a lasting impact on Ames. First, everyone within the NACA became even more sensitive to the verbiage of basic and applied research, so that even today people at Ames wax fluent on their place within the research spectrum. Second, Ames staff had no time to get grounded in the place before being swept up into war work.

]War Work[

Even before Congress had finalized its funding, the NACA was ready to start work on the Sunnyvale site. By 6 December 1939 the NACA had worked out an agreement with the War Department over 43 acres at Moffett Field tentatively called the Aeronautical Research Laboratory, Moffett Field. Ground was broken on 20 December 1939 for a solitary wooden construction shack to house the small staff on-site, supervised by Russell Robinson. Meanwhile, DeFrance returned to Langley where he was hand-picking his research staff and overseeing their designs for facilities at the new laboratory.

The first permanent staff arrived at Ames on 29 January 1940, led by John Parsons and Ferril R. Nickle. Good memories of Stanford University convinced many Langley staffers to relocate to the new laboratory. Parsons had worked closely with William Durand, professor of aeronautics at

Stanford and a leading member of the NACA. More than 20 Stanford graduates filled out the Ames staff within its early years, including Harvey Allen, Walter Vincenti, and John Dusterberry.

In February 1940, construction began on the flight research building; in April, work started on the first of two technical service workshops; in May, work began on the 16 foot high speed wind tunnel, as well as on the first of two workhorse 7 by 10 foot tunnels. In July 1940, DeFrance took over officially as engineer-in-charge and the first test piles were dug for the 40 by 80 foot wind tunnel, larger by a third than the biggest at Langley. Research first began at Ames in October 1940, wind tunnels started returning data, and by the time of the raid on Pearl Harbor, the new laboratory had published its first technical report.

Deicing Research:

The first research effort authorized at Ames focused on ways to defeat the icing menace. Icing was the major impediment to safe and regularly scheduled air transportation, and had already disrupted wartime military flights. Yet little was known about how to knock ice off an aircraft, and even less about what caused it. Lewis Rodert had already started this research at Langley, but thought the weather in northern California was better suited to the study of icing conditions. The flight operations hangar was the first research building opened at Ames, and Rodert based his research effort there. Furthermore, the NACA had followed the deicing work and knew that it was close to producing important results, which would quickly validate their fight for the new laboratory.

To really understand how ice formed on aircraft, Rodert and his group first needed to devise an aircraft that could collect data in even the worst icing conditions. As an expedient to in-flight experimentation, they tried out thermal deicing. They ran hot exhaust gas through the wings of a Lockheed 12A, and discovered that thermal deicing worked well. After first defining the problem, and refining the specific technologies of thermal deicing, Rodert rushed to devising design rules of thumb for those preparing aircraft for war. His techniques for thermal deicing were built into many aircraft important to Allied air operations in World War II, including the B-17, B-24 and various PBY aircraft. Toward the end of the war, Rodert's group focused more on theoretical calculations of the heat required for deicing, though he continued to agitate among aircraft designers for more attention to icing problems.

Rodert won the prestigious Collier Trophy in 1947, soon after he had left Ames for the NACA's Aeronautical Propulsion Laboratory. His work was soon superseded by new technologies, especially those made possible with jet engines. And his work was soon forgotten around Ames. On one hand, his deicing work was atypical of the work then dominant at Ames. Rodert had taken his work much further into practical design issues than the NACA was ever meant to go, and his work had little to do, ultimately, with wind tunnels. In fact, Rodert distrusted the ability of wind tunnels to produce artificial ice anything like natural ice. On the other hand, Rodert had started with a bold theoretical stance, and defended it tenaciously. He paid attention to his research tools, specifically the airborne laboratory that let him prove out his ideas cheaply and quickly. Thus, his research in many ways foreshadowed the Ames way of research.

Wartime Wind Tunnels:

The key component in Ames' research agenda, and its first construction priority, was the 16 foot high speed wind tunnel. Opened in 1941, it proved a remarkably timely tool in refining war-time fighter aircraft. Its test section was four times larger than Langley's 8 foot high speed tunnel and its speed, up to Mach 0.9 or 680 miles per hour, made it the fastest in the NACA and ideal for solving problems specific to air compressibility. The Lockheed P-38, for example, was the first aircraft able to fly fast enough to encounter compression effects. It had a fatal tendency to tuck-under; that is, in a high-speed descent, it nosed over into a vertical dive from which no pilot had the strength to recover. Researchers at Langley investigated and found shock waves along the wing that reduced lift. When they suggested a radical redesign of the aircraft, early in 1943 Lockheed chief Kelley Johnson instead took the problem to Ames. Led by Albert L. Erickson, the 16 foot group found the specific location of the shock wave and showed how it caused flow separation over the wing. This, in turn, removed the downwash on the tail to put the aircraft into a dive; no elevator had enough surface area to allow the pilot to pull out of it. While the complex of aerodynamic factors was fascinating, Ames people understood that the Lockheed engineers looking over their shoulders wanted a quick answer. Erickson explored a number of configuration changes, the simplest of which was a flap under the wing. DeFrance, in reviewing this work, suggested hinging the flap so that the pilot could control the dive. From these insights, Ames developed dive-recovery flaps which were immediately built into the P-38 and the Republic P-47 and later added as safety devices for flight tests of all new fighter aircraft.

Duct rumble on the P-51B Mustang--another example of the utility of the 16 foot tunnel--was so bad that, at 340 miles per hour, flow through the inlet caused the aircraft to buffet dangerously. The president of North American Aviation made an emergency appeal to DeFrance, and one week later the P-51B fuselage was mounted in the 16 foot tunnel and ready for tests. Within two weeks, Ames engineers had successfully modified the shape of the duct inlet. Engineers at North American built inlets according to Ames' design, finished the flight tests, and the P-51B went on to become the fastest and most potent fighter plane in Europe.

There was nothing especially sophisticated about Ames' twin 7 by 10 foot wind tunnels. "Workhorse" was how they were most often described. But from the time they opened in the fall of 1941 they were kept in almost constant use, mostly to correct design faults in new military aircraft like the B-32 and the XSB2D-1. Because models used in these low-speed tunnels could be made entirely of wood, it was cheap and easy to run tests there. Ames staff always found ways to squeeze time from the 7 by 10 foot tunnels for basic research. There they pioneered the use of electrical motors on models to simulate propeller flows, then studied the debilitating effects of propeller slipstreams.

Many of the 7 by 10 foot tunnel staff moved over to the 40 by 80 foot wind tunnel when it opened in June 1944. Harry Goett led the new full-scale and flight research branch, which included flight test aircraft. The 40 by 80 was best suited to aircraft development work, rather than basic research. The first series of tests was for the BTD-1 Destroyer, a rather ambitious fighter designed by Douglas Aircraft. After countless hours of testing at Ames, the Navy lost interest in the BTD-1 as the war came to a close. Other aircraft tested there included the Northrop N9M-2 flying wing prototype, the Grumman XF7F-1 Tigercat, the Douglas A-26B low-level bomber, and the Ryan XFR-1. Where the 40 by 80 distinguished itself most was in the study of complex airflows and handling qualities at slow speeds.

Flight research complemented all facets of Ames tunnel research, and Ames aerodynamicists constantly checked data generated in the wind tunnels to see how well it agreed with data generated in free flight. For example, Ames staff, working at the NACA high speed flight research center at Rogers Dry Lake, California, calibrated tunnel and flight data using their P-51 aircraft. They removed the propeller from the P-51 so the aircraft would be aerodynamically clean like a tunnel model. Another aircraft towed it to altitude, released it, and Ames test pilot James Nissen guided it to a landing while recording air flow data. Drag flow and all other measurements correlated superbly with data generated in the 16 foot tunnel.

Handling Qualities:

With the wealth of data collected on the P-51 flights, Ames engineers moved into research on handling qualities. During the war, Ames had tested a wide array of different military aircraft in its 7 by 10 foot tunnels. Although these tunnel tests were meant to solve specific problems of stability and control, the Ames aerodynamicists began to see patterns in the problems. Ames test pilot Lawrence Clousing, working with William Turner and

William Kaufmann, led early efforts at describing in objective and universal terms the handling qualities of aircraft for handbooks on specific aircraft. In the early 1950s, Ames investigated handling qualities more systematically, in order to develop a guide for evaluating new military aircraft. Three Ames pilots flew ten different aircraft in 41 different configurations to determine, first, the safe minimum approach speed for aircraft landings and, second, any more general stability and control issues. From these test flights, pilot George Cooper devised a standard ten-point scale for rating handling qualities that assessed the difficulty of maneuvers, the aircraft's behavior, and pilot accuracy. The Cooper Pilot Rating Scale, published in 1957, standardized handling qualities assessments across the industry and around the world. (It was revised in 1969 by Robert Harper of Cornell Aeronautical Laboratory, and is now called the Cooper-Harper Handling Qualities Rating Scale.)

The Ames flight research group also pioneered variable stability aircraft. In 1948, a group led by William Kaufmann altered a Grumman F6F-3 fighter by adding servo-actuators to the ailerons so that the pilot could modify the dihedral of the wing (whether it slants upward or down). They added a drive to the rudder so the pilot could vary directional stability and damping, and soon devised other mechanisms so the pilot could vary six key stability and control parameters. For the first time, aerodynamicists could change flying qualities, even in flight, without changing the aircraft’s configuration. Ames aerodynamicists could easily explore flying qualities of any aircraft then under design. For example, as a result of pilot comments during variable stability tests on the F6F-3, Ames suggested that Lockheed design the F-104 with ten percent negative dihedral. To improve military specifications on flying qualities, Ames later applied the concept to such aircraft as the F-86D, the F-100C, and the X-14.

12 Foot Pressurized Wind Tunnel:

Ames' most sophisticated facility for calibrating tunnel tests with free flight was the 12 foot pressurized, low turbulence tunnel. It opened in July

1946, and stood as the culminating achievement of subsonic tunnels. Pressurization directly addressed the issue of Reynolds number. Is one justified in drawing conclusions about the properties of large bodies, like aircraft, from tests on smaller objects, like models? That is, are there scale effects because of the thickness of air? A Reynolds number is a statement about the relationship between the four properties that affects the flow of a fluid about a body moving through it--the size of the body, and the air's velocity, density, and viscosity--and most simply it expresses the ratio of aerodynamic forces to inertial forces. Tunnel tests are comparable only when the Reynolds numbers are the same. To get numbers to compare tunnel scale models and full size aircraft, researchers must make the air in the tunnel more dense. Thus to compare data from an aircraft flying at 800 miles per hour, with a 1/5th scale model aircraft also at 800 miles per hour, the air pressure must be raised fivefold. This was the thinking behind the pressurized wind tunnel.

Building the pressurized tunnel was an engineering marvel. Because the hull had to withstand five atmospheres of pressure, the steel plates in some places of the hull were two inches thick. The pylons on which the 3,000 ton hull was mounted were hinged to allow for expansion during heating and pressurization. Instead of the usual sharp 90 degree angles to turn around the airstream, the hull turned it around in small angular steps. Finally, to improve the uniformity of the flow, Ames built a 43-foot diameter sphere just before the test section to hold a fine-mesh anti-turbulence screen.

The 12 foot tunnel was used immediately to explore the performance of low aspect ratio wings, swept wings and delta wings like those used in the Air Force's Century series of fighters. And it was used in basic research where scale effects mattered--like in the design of wing flaps and laminar flow control devices. Most important, it allowed closer correlation between results from wind tunnels and flight tests.

]DeFrance, Parsons, Goett and Allen[

The Ames work force grew rapidly during the war and afterward, from 50 in 1940, to 500 by 1943, to 1,000 by 1948. As the number and variety of researchers at Ames expanded, its organizational chart grew more complex. However, the structure of leadership at Ames remained fairly clear. During Ames' first two decades, four men formed the contours of its organizational culture--Smith J. DeFrance, John F. Parsons, Harry J. Goett, and H. Julian Allen.

Smitty DeFrance, the director, was a pillar of integrity, a conscience of conservatism, and a reminder that everyone at Ames worked for a greater good. DeFrance had served as a pilot during World War I then earned a bachelors degree in aeronautical engineering from the University of Michigan. He joined the Langley Laboratory in 1923, designed its 30 by 60 foot tunnel, and rose to lead its full-scale wind tunnel branch. Before Congress had even funded Ames, he led design studies for its first tunnels, and was named the laboratory's founding engineer-in-charge. DeFrance received the Presidential Medal of Merit in 1947 for designing and building the laboratory. His title was changed to director, a position he held until his retirement in October 1965.

DeFrance stayed close to the Ames headquarters building, where few of his staff ever went. DeFrance's management style has been described as that of a benevolent dictator who patrolled Ames' boundaries. NACA headquarters largely demanded that of its directors: only one voice should speak for the laboratory so all contact and correspondence went through his office. In turn, he shielded his research staff from outside pressures, created an atmosphere of freedom, and allowed the laboratory to evolved like a think tank. When DeFrance did have contact with his research staff, it was to inquire about contingency or emergency plans, the public value of a project, or how certain his staff was of their conclusions.

Perhaps because he had lost his left eye in a airplane crash at Langley, DeFrance insisted on extraordinary safety measures. It was DeFrance who insisted that the pressure hull of the 12 foot wind tunnel be tested hydrostatically--that is, by filling it with 20,800 tons of water to see if it would burst. Later, DeFrance was in the control booth as engineers cautiously started turning the fan blades for the first time. "What's that red lever for?" DeFrance asked above the rising roar of the motors. "An emergency shut-off," yelled back an engineer. DeFrance leaned over and pulled the lever. The engineers just stared as the fragile blades shuttered to a halt. "Don't you think you should be sure that the shut-off works," Smith said, "before you need it?"[3] No one ever questioned DeFrance's experience.

Also because of his airplane accident, DeFrance promised his wife he would never fly again. Since the train trip to Washington took four days each way, he seldom went there. This created a curious situation in that the person responsible for speaking for Ames with NACA headquarters and other federal agencies actually did so rarely. Yet when DeFrance did speak to people in Washington, they listened. As the younger scientists at Ames grew more ambitious after the war, they often felt that their colleagues at Langley took unfair advantage of their proximity to Washington to press their own plans. In fact, DeFrance knew that distance also had its advantages in creating space for basic research. Plus, DeFrance had ambassadors in key places. In 1950, Russell Robinson returned from NACA headquarters to serve as Ames' assistant director alongside Carlton Bioletti. Robinson, especially, continued to improve Ames' relations with Washington. Edwin Hartman, who served from 1940 to 1960 as the NACA's representative among the airframe manufacturers of southern California, served as DeFrance's ambassador to the various facets of the aerospace industry.

Jack Parsons was the builder. He arrived in January 1940 with the pioneer detachment from Langley. He oversaw the entire construction effort, became DeFrance's principal assistant, and stayed as associate director until his retirement in 1967. A native of Illinois, Parson moved to Stanford University to take a bachelor degree, the professional degree of engineer, and to work with William Durand in editing his classic six-volume work titled *Aerodynamic Theory*. Joining Langley in 1932, he oversaw the design and construction of the 19 foot pressure tunnel. At Ames, in addition to serving as chief of the construction division, Parson became chief of the full scale and flight research division.

Though trained in aerodynamics, Parsons had an intuitive understanding of how to pour concrete, weld steel, and get every part of a construction team pulling together. He was the exemplar of Ames project management style, able to complete projects on time, with ingenious engineering twists that saved money and kept the scientific results foremost. NACA headquarters turned to Parsons to lead its Unitary Plan Wind Tunnel effort, which was conceived as the biggest single construction project in NACA history. As construction around Ames slowed its breakneck pace, Parsons turned his attention to the administration of the laboratory. As chief administrator, he saw the big picture and brooked little inefficiency. To the junior staff his presence served as a constant reminder that they, indeed, worked for the federal government, with an ultimate responsibility to the American public. He was a quiet operator, intensely loyal to DeFrance, and widely respected for his skills.

Harry Goett championed applied research and served as an early model of career reinvention at Ames. A native of New York, he earned his degree of aeronautical engineer from New York University at the nadir of the depression. He worked at a handful of companies as a mechanical engineer before joining DeFrance's branch at Langley in July 1936. He arrived at Ames in July 1940, designed model supports, then directed research in the 7 by 10 foot workhouse tunnels. He took charge of the 40 by 80 foot wind tunnel when it opened in 1944, and in 1948 he took over Parsons' role as leader of all full scale and flight research. He remained there until July 1959, when he was named founding director of the new Goddard Space Flight Center.

Goett understood that he supervised the most sought-after set of research facilities in the world, and he strove constantly to keep them in good use. Aircraft companies might ask Goett's group to solve routine problems of control and stability, but Goett never allowed his people to see their work as routine. He constantly urged them to envision new opportunities for basic research, to look at the bigger picture of what they were learning. This ability to see new patterns in routine work led to Ames' long-running work in handling qualities and variable stability aircraft.

Goett moved his group into research on space vehicles long before that work fell under the NACA's purview. He encouraged Jackson Stadler to pursue plans for a low density wind tunnel, opened in 1948, to explore aerodynamics where there is no air. Goett became the NACA's technical liaison to the West Coast manufacturers of satellites and space probes, and became an expert on launch systems and instrumentation for space systems. While remaining firmly within the management ranks, Goett had reinvented himself as an expert on space technology.

Goett kept his staff alert and moving ahead. He made his people understand why they were running every test, starting with a complete analysis of the problem, using the best tools of aeronautical science, so that the tunnel tests simply provided numbers for the tables. His infamous bi-weekly meetings for each branch in his division took on the air of inquisitions, as peers questioned every part of an investigation. Sharing trepidation over their day on the block built substantial esprit de corps. Often Goett suggested a novel way to resolve an intractable problem, though his name appeared on far fewer research papers than he contributed to. He was never in competition with his staff.

As a person, Goett took pride in the profession of engineering, and got along well with pilots. He was cut from the same mold as DeFrance, straight-laced, soft spoken, pragmatic, and authoritative. By contrast, there was Harvey Allen, and the men who followed his lead were a very different breed.

Harvey Allen pushed the limits, in scientific creativity as well as in social behavior. Allen was emotionally involved with his work. He never let the paperwork thrust upon him during his rise through the ranks interfere with his compulsive urge to explore the nature of air himself. This endeared him to the growing numbers of researchers at Ames.

Allen was born in Illinois, in 1910 and, like so many early Ames employees, earned his bachelor and engineers degrees from Stanford University. Upon graduation in 1936, he joined the NACA at Langley and developed a general theory of subsonic airfoils that helped to dramatically improve low-drag airfoils. Allen moved to Ames in April 1940 to lead the theoretical aerodynamics section, reporting to Donald Wood. Allen spent as much time designing as using the new wind tunnels. He conceived many of the throat designs and turbulence screens that allowed Ames wind tunnels to reach faster speeds with better results. In July 1945, Allen was named chief of Ames' new high speed research division, where he remained until further promotion in 1959.

High speed meant supersonics and hypersonics, speeds that were then only theoretical. Allen developed a now well-known theory for predicting forces at supersonic speeds at various angles of attack, a theory that proved especially useful in designing missiles. He devised theories of oscillating vortices, of heat transfer and boundary layers, and of the interaction between shock waves and boundary layers.

But Allen was no mere theoretician. He knew it would take decades for theories of supersonics and hypersonics to catch up with the reality he would forge in the meantime. Allen designed two types of supersonic nozzles that made Ames' wind tunnels more flexible and effective. He designed two methods for visualizing air flows at supersonic speeds, and devised techniques for firing a gun-launched model upstream through a supersonic wind tunnel.

Allen will be remembered best for the insight known as the blunt body concept for solving reentry heating. He published a paper in 1951, jointly with Alfred Eggers, in which they suggested that a blunt shape was better than a pointy shape for getting a body back into Earth's atmosphere without it burning up. This insight was counter-intuitive. Most other researchers assumed that a design should minimize the contact between object and air to reduce the heating; Allen and Eggers knew the air would carry aways its own heat if all the shock waves were designed right. Having advanced his theory, Allen marshalled every possible resource to prove it. He built wind tunnels capable of hypervelocities, arc jets capable of high sustained heat, and flight research vehicles that pushed the envelope of space. Every human-made object that reenters Earth's atmosphere--ballistic missiles, manned space capsules, the space shuttle--does so safely because of Allen's passion for his research.

There were a great many giants in these formative years of Ames history--Helen Davies became division chief for personnel; Marie St. John was DeFrance's administrative assistant; Larry Clousing, Bill McAvoy, Steve Belsley, and Alun Jones ran flight operations; Donald Wood and Manley Hood ran the theoretical and applied research division; Dean Chapman and Max Heaslet were world-renowned theoreticians. To the world outside, DeFrance and Parsons were the face of Ames. But those working Ames' wind tunnels placed themselves in either Goett's or Allen's camp. And the (always friendly) tension between Goett and Allen defined the character of the place.

Where Goett had a passion for excellence, Allen had a passion for ingenuity. Said Bill Harper, who took over the 40 by 80 foot wind tunnel from Goett: “The educational impact on a young engineer, caught between these two, each arguing his case in a most convincing way, was enormous. To strengthen his case, Harvey was always holding parties at his home which quickly turned into intense technical arguments....No matter who you worked for, you could expect to find Harvey dropping by to learn of your progress and constructively criticize what you were doing.”[4]

Harvey Allen was a modern renaissance man: a lifelong bachelor, a world traveller, collector of ethnic arts, a lover of fine automobiles, a bon vivant with a creative and cultured mind, a hard drinker, and host of legendary parties. He animated lunchtime conversations at the Ames cafeteria. Allen had a warm sense of humor that blended nicely with his highly creative mind and his informal and sincere approach to people. Allen's final research project was on the slender feather protruding in front of an owl's wings, which he suspected enabled owls to fly so silently. As a testimony to how much fun Allen made Ames as a place to work, a group of Ames alumni continue to meet, calling themselves The Owl Feather Society.

Harvey Allen had a nickname for everybody, often the same name. After he went a year of calling everybody Harvey, after the character in a popular play, the name stuck to him. (The H in H. Julian Allen was for Harold. His family called him Julian.) In 1952, Ames hired a mathematician with a Ph.D. and Allen started greeting everyone jovially as “my good doctor.” One day his group sat at the start of a meeting and in walked Milton van Dyke who was young and looked even younger. When Allen called out, “My good doctor van Dyke!” the mathematician, who had not yet caught on to Allen’s conviviality, exclaimed, “My god, does everyone here have a doctorate?”[5] Those there broke into laughter. In fact, none of them had doctorates, and it didn’t matter. The atmosphere was open to anyone with good ideas.

Into Supersonics

In May 1944, DeFrance and Allen first proposed to NACA headquarters a supersonic tunnel with a test section that was big enough for a man to work in. Researchers using the 1 by 3 foot supersonic tunnel could detect shock waves, but they could not use models big enough to collect pressure distributions. NACA headquarters shelved the plan for the larger tunnel, claiming lack of funds. Some months later an engineer from the Navy Department showed up seeking advice on a supersonic tunnel they had hoped to build. Headquarters staff, looking prescient indeed, pulled the Ames design out of a drawer, and by January 1945 the Navy had transferred funds to get this tunnel built. Carlton Bioletti immediately started detailed design, and the 6 by 6 foot supersonic tunnel made its first trial run on 16 June 1948. Charles Frick ran the tunnel, which was used to test every major jet aircraft and guided missile of the 1950s--for drag reduction, stability and control, and inlet design.

However, researchers were annoyed that the tunnel could not obtain data in the transonic range: it operated subsonically from Mach 0.6 to 0.9, and supersonically from Mach 1.2 to 1.9. Charles F. Hall led studies on a modification of the tunnel, completed in April 1955, that produced speeds continuously from Mach 0.65 to Mach 2.2. As faster tunnels, like the Unitary, came on line for development tests of operational aircraft, Ames used the 6 by 6 foot tunnel more for basic research in conical camber, vortex flows, canard-type controls, and inlet design for supersonic speeds.

Ames pioneered another facility for gaining data on transonic aerodynamics. In 1946, the Ames flight engineering section, led by Alun R. Jones, devised a way to build free-fall models and recover them, at a fraction of the time and cost of building rocket-boosted models. Ames developed 107 models and recovered 95 of them. These were mostly full-scale models weighing up to a ton. After the flight tests, the models decelerated from transonic speeds so that a parachute could deploy, then landed on a nose spike which penetrated the ground. These models proved important in validating data on transonic drag-rise which led to the theory, developed by Robert T. Jones at Ames, of the supersonic area rule. Ames' recoverable model group established a method for calculating optimal fuselage shapes at specified speeds and showed, by comparison, how tunnel walls and Reynolds number skewed design data. And they measured the values of engine air inlets, which must be tested at full size because of their extreme sensitivity to boundary layers.

Solving Jet Problems:

The Lockheed P-80 Shooting Star was the first American airplane designed from scratch for jet propulsion, and thus the first to encounter the problem of transonic flutter--a fast vibration in the ailerons. Using the full speed of Ames' 16 foot tunnel, researchers first discovered that the wing, did not generate this aileron buzz as it traditionally did. Then they explained the problem theoretically, gathered empirical data, suggested methods of dampening it in other aircraft, and flight tested their ideas. Wing-body-tail interference, as another example of how Ames solved problems of supersonic flight, arose because jet bodies and tails were larger relative to the wing in order to provide stability over a wider range of speeds. Jack Nielsen led a group devising interference theories that were tested by comparing theoretical results with tunnel data.

Ames' work on supersonic aircraft focused first on the sort of work NACA had always done for America's aircraft industry, devising more efficient wings. Robert T. Jones arrived at Ames in August 1946 after distinguishing himself at Langley as the American inventor of the swept wing. Jones was a self-taught mathematician with a flair for aerodynamics. He became a protégé of theoretical aerodynamicist Max Munk and often claimed he was only extending Munk's ideas, though the clarity with which he expressed those ideas convinced everyone at Ames that Jones was his own genius. With his work on low aspect ratio wings, for example, Jones continued to show that the shapes of wings to come were far more than the assembly of airfoil sections--as NACA work at Langley had long ago proved. In jet aircraft, airfoil shapes blended into a new conception of the whole lifting surface--planform, sweep, aspect, aeroelasticity, all interacting in complex ways.

What Jones brought to the distinguished group of theorists at Ames--including Max Heaslet, Harvard Lomax, Milton Van Dyke, and John Spreiter--was an intuitive feel for the importance of Mach cones (that is, the shock waves that spread like a cone back from the front of an aircraft). Ames had already begun studies on swept-wing planforms that looked like arrowheads--long and slender with the leading edges swept back as much as 63 degrees. Jones encouraged even more dramatic sweep, to 80 degrees, then devised theory supporting tests on triangular and delta-wing planforms. For example, Elliot Katzen led tests in the 1 by 3 foot supersonic tunnel, in 1955 and 1956, to determine which arrowhead shapes had the best possible lift-to-drag ratios at Mach 3, the cruise speed expected for a planned supersonic transport. Katzen had already designed five wings, using linear theory, with a similar arrowhead planform but differing twists and cambers. Jones consulted on the project, suggesting a planform swept back far enough behind the Mach cone so that the Mach number perpendicular to the leading edge was similar to that of the Boeing 707 in flight. He also suggested a Clark-Y airfoil with camber but no twist. When the thin metal model arrived from the model shop, Jones twisted the tips by hand until it looked right to him. This wing returned a lift-drag ratio of 9--the best efficiency ever measured for a wing travelling at Mach 3.

In 1952, Jones looked over the theory of the transonic area rule, which designers used to reduce the sharp drag rise at transonic speeds by controlling the simple cross section of the aircraft. Jones quickly devised the supersonic area rule, which led to designs that reduced drag at supersonic speeds by controlling the cross section of the aircraft cut by Mach cones. The big advantage of Jones' approach was that it was readily applicable to complete aircraft, including those carrying external weapon stores or fuel tanks.

Early in 1949, the research staff of Ames' 6 by 6 foot supersonic tunnel--Charles Hall, John Heitmeyer, Eugene Migotsky, and John Boyd--concluded that dramatically new wing designs were needed to make jet aircraft operate at top efficiency. Theoretical analysis pointed them to a special form of camber--a slight convex curve--small at the root but increasing in depth and width toward the wing tip like the surface of a conical section. Experiments begun in 1950 confirmed their theoretical predictions of more uniform loading along the span. In 1953, at the early stages of its design, the Air Force asked Ames to study the disappointing efficiency of the Convair B-58 Hustler supersonic bomber. Hall's group designed a wing with conical camber that dramatically improved the range of the B-58, which in turn pioneered the design of all future supersonic transports. Likewise, the first Convair F-102 Delta Dagger was flown without conical camber in the wings. Ames showed that conical camber gave it an enormous improvement in range without diminishing its speed. Camber was built into all subsequent versions of the F-102. Overall, Ames tested 29 different aircraft to measure the improvements from conical camber.

The fastest jet wings were also the smallest, but small wings had trouble providing lift at slow speeds. Aerodynamicists at Ames refined the old ideas of boundary-layer control by applying suction or blowing to delay stall and give higher lift coefficients at low speeds during take-off and landing. Using the 7 by 10 foot tunnels, Ames researchers classified three types of stall encountered by airfoils, leading to better high-lift devices for aircraft. Using the 40 by 80 foot tunnel, Charles "Bill" Harper and John DeYoung tested the validity of the idea on entire aircraft. Using an old F-86 and mechanical techniques devised during Ames' earlier work on thermal deicing, Woody Cook, Seth Anderson, and George Cooper collected data for a landmark study on flap suction.

The staff of Ames' 1 by 3 foot supersonic tunnel, who did more basic research as more development testing was moved to the 6 by 6 foot tunnel, led research into viscous flows. Dean Chapman, of the 1 by 3 foot branch, started work in 1947 on the effects of viscosity on drag at supersonic speeds, then returned to the California Institute of Technology to write up these data as his doctoral dissertation. His theoretical work led him to predict that blunt trailing edges worked better than sharp edges in minimizing viscous flows, which he verified experimentally. Those experiments generated data on base pressures that provided tools designers could use to optimize the shapes of the back ends of aircraft--the aft part of the fuselage and trailing edges of the airfoil. In 1949, Chapman published a simplifying assumption, on the relationship between temperature and viscosity, that allowed better calculations of laminar mixing profiles and boundary layers. Chapman then continued his work on boundary layers, and supervised work that led to measurements of turbulent skin friction at Mach numbers up to 9.9 and at very high Reynolds numbers. He reached these high Mach and Reynolds numbers by constructing a boundary layer channel using high pressure helium as the test fluid. He then developed an equivalence relationship between helium measurements and air values. He matched those measurements with determinants of skin friction made at low Mach numbers by Donald Smith working in the 12 foot variable density tunnel.

Dynamic stability--that is, constantly changing relationships between the axes of motion--arose as another issue of high-speed flight. At subsonic speeds, static stability of the aircraft could be easily checked during tunnel tests. Jet aircraft, however, had entirely new shapes, aerodynamic coefficients, and mass distributions. Testing dynamic stability on jets was complicated work. Ames had to find the aerodynamic moments acting on models while they were rotating or oscillating about various axes. Benjamin Beam developed a technique for spring-mounting models, imparting an oscillation, then measuring these dynamic aerodynamic moments. He simplified the data processing by building an analog computer into the strain gauge circuitry. With this apparatus, Ames tested the dynamic stability of every new military aircraft in the 1950s.

Ames also addressed the complex airflow through jet air inlets. Jet turbine engines required much larger volumes of air than reciprocating engines, while also being more sensitive to the speed and turbulence of that air. The first jet aircraft inducted air through the nose, in part because the designers could rely on a wealth of NACA data on cowlings for reciprocating engines. When designers needed the nose for armament or radar, air intake scoops were moved back and submerged, following a design suggested by Charles Frick and Emmet Mossman working in the Ames 7 by 10 foot tunnels. Inlet design remained simple so long as jet aircraft remained subsonic.

For supersonic inlets, designers needed entirely new design principles and practices. Ames played a role in the design and testing of inlets for every early supersonic jet. Ames learned much from its work on the McDonnell F-101 Voodoos, which had been designed for subsonic flight until a better engine made supersonic flight possible. Ames quickly discovered what made inlets transition smoothly from the subsonic to the supersonic regime--attention to boundary layer removal, internal duct contours, and planned interaction between boundary layers and shock waves. Mossman devised a variable throat area that allowed for proper operations at any speed, and others at Ames continued their basic research into internal shock waves. As speeds approached Mach 2, jet designers started to use Ames data on supersonic compression within the duct.

]Unitary Plan Wind Tunnel[

At the close of World War II, American aerodynamicists reflected on where they stood. They were surprised at how well British aerodynamicists had performed with limited resources. But they were amazed when they finally saw what German scientists had been working on--like jet propulsion and supersonic guided missiles--and concerned that a good many German scientists were now hard at work for the Soviet Union. American aerodynamicists felt that their pool of basic research had been exhausted while they solved urgent wartime problems. The NACA and the U.S. War Department independently decided that America needed to address the dawn of supersonic flight with more than fragments of theories and small scale tests.

NACA and military officials met in April 1946 and agreed on a "unitary plan" for new facilities. They asked NACA member Arthur E. Raymond to head a Special Panel on Supersonic Laboratories, with members from the NACA, the Army, the Navy, airframe companies, and engine companies. The Raymond Panel report led to a new NACA Special Committee on Supersonic Facilities headed by Jerome C. Hunsaker. In January 1947, the Hunsaker Committee submitted its unitary plan, that was scaled back by the U.S. Joint Research and Development Board to the most urgent facilities. The NACA got permission from the Bureau of the Budget to submit Unitary Plan legislation to the House and Senate. It passed and was signed into law by President Truman on 27 October 1949. Under Title 1 of the Unitary Wind Tunnel Plan Act of 1949, NACA was to get $136 million for construction of facilities. Yet, when they first reviewed this budget on 29 June 1950, Congress halved the authorization to $75 million. Now, rather than including facilities for the newly formed Air Force, the unitary plan would only serve the combined interests of the three NACA laboratories. A year later, Congress again halved the appropriation and Ames prepared to lead the effort alone.

NACA Director Hugh L. Dryden established a NACA-wide project office for the unitary wind tunnels, headquartered at Ames and led first by Jack Parsons and soon thereafter by Ralph H. Huntsberger. Huntsberger solicited suggestions from Langley and the Lewis laboratory, to make one complex of supersonic tunnels embody the ambitions of a nationwide plan. Construction began in 1951 at a cost of $32 million. After a six month shake-down, starting in June 1955, the tunnel opened with a test of the inlet design for the aircraft that became the McDonnell F-4 Phantom, the first designed for cruising at Mach 2 and the first to be procured by each military branch.

"Unitary," in addition to describing the tunnel's political aspirations, also described the integration in its basic design. The Unitary facility covered 11 acres, and consumed an enormous amount of electricity. It embodied three large test sections, powered by two large axial flow compressors that drove air over the Mach range of 0.3 to 3.5. A three-stage compressor drove air into a transonic section that was 11 by 11 feet, and an 11-stage compressor forced air through a rotating flow diversion valve into two supersonic sections that were 9 by 7 feet and 8 by 7 feet, respectively. Significantly, the speeds of the three test sections overlapped so that a single model could be tested over this entire range.

Each component of the Unitary pushed the state of the art in wind tunnel design. It embodied the largest diversion valves ever built, at 20 and 24 feet in diameter. Each weighed 250 tons, could be rotated in 25 minutes, and was airtight. The compressors were built by the Newport News

Company. The rotor for the smaller compressor was, as of 1955, the largest cargo ever received at the Port of Oakland. The compressors were powered by four intercoupled motors built by General Electric, that were then the largest wound-rotor induction motors ever built. They were tandemly coupled between the two compressors, so that within 30 minutes, the motors could be disconnected from one compressor and connected to the other. Two of the motors had electrodynamic braking to slow the inertia of the compressors in case of emergency. The shafts carried the largest load of any tunnel shaft in the world. To reduce bending stress on the shafts, the entire drive train was supported by a single foundation.

The tunnel shell was a pressure vessel, constructed of steel up to 2.5 inches thick. Each test section had a separate nozzle configuration to match the Mach number required. The 11 foot tunnel had a simplified design, using a single jacking station to deflect a variable moment-of-inertia plate. A bypass valve equalized pressures between sections while a make-up air system controlled the temperature and humidity of the tunnel air by using intercoolers, dry air storage tanks, and evacuators. Dried air was pumped into storage tanks in a volume equal to that of the tunnel while humid air was evacuated. This controlled humidity to 100 parts per million of water, controlled stagnation pressure to 0.1 to 2.0 atmospheres, and greatly improved the Reynolds numbers attained.

The most important aircraft of the 1950s and 1960s were tested in the Unitary. In addition, Ames researchers explored the basic problems of the boundary layer, the mechanism of transition from laminar to turbulent flow, and the dynamic stability of various shapes used for warheads on ballistic missiles. Over the next four decades, the Unitary remained in almost constant use solving the evolving problems of supersonic flight. (And in May 1996, it was dedicated as an International Historic Mechanical Engineering Landmark by the American Society of Mechanical Engineers.)

]Transonics[

It is, perhaps, a testament to the experimental facilities at Ames that theory lagged far behind empirical advances in supersonic aircraft. In theory, it might seem be no harder to theorize about the aerodynamic properties of bodies at transonic speeds--the speed range near Mach 1--than it is at subsonic or supersonic speeds. Yet prior to the late 1940s, nature revealed no solutions to either the theoretician or the experimenter. As a monument to nature's reluctance, there was a great store of experimental data that terminated at some Mach number close below 1, or started close above Mach 1. Furthermore, there were many theoretical predictions that simply did not agree with any experimental observations. Two developments in the late 1940s started to bring unity to the data above and below Mach 1. First was the development, by John Stack and his colleagues at Langley, of transonic tunnels with slightly open walls. Second was the small disturbance theory of transonic flow, advanced by work at Ames.

To move the calculations on small disturbance to the next level of approximation, transonic theory for two-dimensional flow required solution of a difficult nonlinear partial differential equation of a mixed elliptic-hyperbolic type. Walter Vincenti in the 1 by 3 foot tunnel attacked this problem using the hodograph method--a concept that had been explored by the Italian mathematician Tricomi in the 1920s--that transformed an intractable nonlinear equation into a more manageable linear equation. John Spreiter at Ames then summarized the basic equations needed for a useful approximation for Mach numbers nearly equal to unity. This allowed for fairly accurate prediction of transonic flows past very thin wings and slender bodies.

Max A. Heaslet, one of the few people at Ames to have a Ph.D., in mathematics, led the laboratory's theoretical aerodynamics section from 1945 to 1958, which did almost all the theoretical work that was not otherwise done separately by R.T. Jones. Heaslet's section undertook the systematic study of wing planforms for supersonic flight, and produced some exhaustive theoretical research on suggested wings in both steady and unsteady flows.

This work on planforms was complemented by Spreiter's similarity laws and the forward and reverse flow theorems advanced by Heaslet and Spreiter and by Jones. Heaslet and Harvard Lomax, coupled with independent work by R.T. Jones, developed practical applications of theories of wing-body interference arising from the transonic area rule.

Milton Van Dyke developed a similar theoretical foundation for hypersonic flight. In 1954, he published the first-order small disturbance hypersonic equations useful as a guide in designing thin wings and bodies. Assisted by Helen Gordon, Van Dyke undertook the prediction of flow around the front of blunt-nosed missiles, an analysis so complex that he and Gordon relied upon electronic calculating machines. Alfred Eggers led another group that applied to hypersonic speeds the classic shock wave and expansion equations for supersonic flows. The criteria for applying these equations was the exact opposite of the small-perturbation methods, namely that the flow disturbance created by the body would be large. This generalized shock-expansion method was shown to allow rapid computation of a variety of hypersonic flows. Clarence Syvertson and David H. Dennis then improved the equations to develop a second-order shock expansion method for three-dimensional bodies. Flight in the hypersonic regime, because of work done at Ames, would have firmer theoretical foundation as tunnel and flight tests began. Plus, Ames had shown how researchers with different skills and interests, concerned with separate but related issues, could calculate ever-better approximations of how real objects would move through real air.

]Hypersonics: Stepping Up to the Space Age[

Aerodynamicists still debate where to put the precise border between supersonic and hypersonic flight. Unlike the sharp jolt as a shock wave wraps around an aircraft near Mach 1, aircraft move gradually from the supersonic to hypersonic regime. Generally, hypersonic flight starts when the bow shock wave wraps closely around the vehicle and this shock wave generates heat high enough that air molecules vibrate, dissociate, and radiate heat and light, which heats up the aircraft structure. Chemical thermodynamics, thus, is as important in hypersonic design as aerodynamics. This heating generally starts at Mach 5 to Mach 10, or at speeds of one to two miles per second. In retrospect, these speeds had obvious importance for design of intercontinental missiles, satellites, and reentry bodies. When Ames started its work, just after the war, chemical thermodynamics was an area of intense theoretical interest that Harvey Allen wanted to trail blaze.

Bringing hypersonic speeds to laboratory research required a stroke of ingenuity. In 1946, Allen suggested firing a model from a gun through the test section of a small supersonic tunnel. Thus, the speed of the model and the speed of the oncoming air combined to produce a hypersonic speed. Alvin Seiff took up the challenge of designing what came to be called, on its opening in 1948, the supersonic free-flight tunnel (SSFFT). The engineering details to be worked out were immense, and challenged every branch of the Ames technical services division. Model shop craftsmen had to build tiny models, no bigger than a .22 caliber bullet, yet sturdy enough to be jolted into supersonic flight. The instrumentation branch had to obtain data from these models in free-flight, that they obtained by rigging the tunnel with a series of very fast cameras and lights.

The full impact of this facility would be known a decade later during the human space missions, but its early use resulted in some important discoveries. The Ames high speed research division discovered an effect of skin-friction drag on turbulent boundary layers that had completely escaped notice in wind tunnel tests. In wind tunnel tests, the models were warmed to the temperature of the test air. In the free flight tests, the model skins were cold compared to the air--a condition comparable to actual flight--resulting in skin friction that was 40 percent greater than measured in tunnel tests. Simon Sommer and Barbara Short used these data to establish a formula to calculate the skin friction of turbulent boundary layers for a realistic range of Mach numbers and temperature conditions.

Another issue that was resolved was the theoretically and practically intriguing one of the transition of boundary layers from laminar to turbulent flow. Since laminar flows conduct less heat and cause less drag than the eddying flow of a turbulent layer, knowing where on a body the transition occurs is important in predicting heating and drag. The supersonic free flight facility was ideal for these studies. In addition to the comparable temperature conditions, turbulence in the free air stream was relatively low since much of the speed was contributed by model motion. Plus, the shadowgraph cameras along the test section took excellent photographs of the state of the boundary layer. What the Ames group discovered was that the transition was unsteady, varying with time, and based on the model's angle of attack. From this, Allen and his group experimentally validated the importance of entry angle in designing missile warheads for laminar or turbulent flow.

Alex C. Charters took up the challenge of devising better guns to propel the free flight models ever faster. In 1952, he designed a gun using controlled explosions of light gas that could propel a test model faster than 14,000 feet per second--two times faster than standard powder guns. Once Charters constructed a prototype of his light-gas gun, DeFrance authorized construction of a hypervelocity ballistic range with a 600-foot long instrumented test range. Based on a challenge from Harvey Allen, in 1956 John Dimeff and William Kerwin of the Ames instrument development branch built a small model containing a calorimeter with a very simple telemetering circuit. Shakeout tests showed that this device could measure the heat transferred in a free flight test with great accuracy. Ames could now measure the temperature environment of the sensitive electronic components in the nose cones of guided missiles. When Ames opened its hypervelocity ballistic range in September 1957, it was used almost exclusively for development tests of guided missiles.

]Preparing for the Space Race[

Ames' work in guided missiles and hypersonics put it in position to play a vital role in the missile race that dominated the aerospace industries around the world in the late 1950s. Ames' labor quota and budget got a short boost during the mini-mobilization surrounding the Korean war in the early 1950s. American military aircraft were then more consistently breaking the sound barrier, oftentimes in combat, which exposed new problems that Ames aerodynamicists were asked to solve. Once the Korean war ended, funding at Ames dropped. In 1953, its labor quota was 1,120, lower than in 1949. Furthermore, because of stagnation in civil service pay rates, DeFrance and Parsons were unable to fill many of the available positions. Soon, Ames would lose even more valuable employees to the high wages in the aerospace industry.

In 1955, President Eisenhower declared that his top priorities would be two intercontinental ballistic missile projects--the Atlas and Titan--and three intermediate-range ballistic missiles--Thor, Jupiter and Polaris. Adjacent to Moffett Field, and far from its tradition-bound facilities in southern California, the new Lockheed Missiles and Space Company built its campus, including a great many clean rooms in which they would construct Polaris missiles for the Navy. Lockheed also built a basic research laboratory that was one of the first tenants in the Stanford Research Park. While much of the work Lockheed did depended on access to the area's fast growing electronics industry, the company also hired many skilled workers away from Ames. Only civil service salary reforms, following the launch of the Soviet Sputnik in 1957, allowed DeFrance and Parsons to stem the flow.

Work poured into Ames as every branch of the military wanted help in designing and understanding its increasingly high-powered missiles. The NACA had embarked on a program to send experimental aircraft to ever-higher altitudes. The Bell X-2 experimental aircraft had already reached an altitude of 126,000 feet by 1956, and the hypersonic X-15 was expected to fly twice as high. Ames' budget soared too, from 1955 to 1958, as the NACA worked on making better missiles. Ames soon fell off this trajectory with the jolts, first, from the reconfiguration of the NACA into NASA and, second, the orientation of NASA around landing a human on the Moon.

Endnotes

[1] Alex Roland, *Model Research: The National Advisory Committee for Aeronautics, 1915-1958*, vol.1 (NASA SP-4103, 1985) 154.

[2] Roland, *ibid*., 160.

[3] Interview with Walter G. Vincenti, 16 June 1999.

[4] "In Memoriam: H. Julian Allen, 1910-1977," *Astrogram* (10 February 1977) 1-3.

[5] Interview with Walter G. Vincenti, 16 June 1999.